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Investigation of The Heating of Greenhouses with solar Energy in The Province of Mersin

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Abstract – These days, there are certain practical and financial challenges even if harnessing solar energy for greenhouse heating has become increasingly important. The initial investment cost of solar heating systems is proportionately higher than that of typical heating systems. The greenhouse absorbs solar radiation to partially meet its heat requirement during the day when the outside temperature is lower than the internal temperature. Within the natural energy sources that can be utilized to heat greenhouses, solar energy may be the most practical. In this study, this approach to greenhouse heating was investigated. The purpose of the study was to determine whether solar energy could be used to heat a two layers plastic greenhouse for 500 square meters in the province of Mersin. A thermal analysis of the planned greenhouse was also carried out. It is established that the plastic greenhouse needs a temperature of 1 °C outside and 15 °C inside. Additionally, CFD (Computational Fluid Dynamics) analysis was examined for the greenhouse model. Furthermore, during January, the coldest month, the average daily heating requirement for total daily heat was calculated to be 60 kW. It has been concluded that the plastic greenhouse should employ 51 mm diameter pipe that is 750 m long. It was concluded that the heat collection unit should employ 32 flat solar collectors in total, each with an absorber surface area of 1.8 m2.

Keywords – Energy, Solar Energy, Greenhouse Heating, CFD Analysis

I. INTRODUCTION

In the current era of high energy costs, heating greenhouses to meet the optimal needs of plants is a costly endeavor. We only use heating in our greenhouses to prevent frost because of this. The resultant low yield and poor quality of the items is caused by this circumstance. In controlled greenhouses, the percentage of production costs devoted to heating has risen to 60%. Lowering this percentage will boost corporate earnings in the greenhouse industry, which has a lot of promise for the agricultural sector and will also greatly boost the national economy. Therefore, to reduce greenhouse heating costs and the use of increasingly finite fossil energy supplies, emphasis should be placed on the use of renewable energy sources in greenhouses. Renewable and clean energy sources include solar, wind, biomass, geothermal, and hydraulic (water) resources. Fossil fuels, on the other hand, are non-renewable and exhaustible when consumed. Renewable energy sources must be used to successfully prevent environmental issues brought on by the direct or indirect use of fossil fuels. However, depending on local circumstances, different renewable energy sources have different economic viability and use in the agriculture industry. Solar, wind, geothermal, and biomass (biogas) energy are the primary renewable energy sources that have applications in the agriculture industry [1].

Greenhouses are facilities where environments suitable for plant growth are created by controlling climate-related environmental conditions. Creating optimum conditions in the greenhouse is only possible by equipping greenhouses with systems such as heating, cooling, lighting, ventilation, and humidification. Today, cultivation is done in automatic and fully controlled greenhouses in countries with cool climates, such as England and the Netherlands. In countries in the temperate climate zone, including our country, greenhouse cultivation has developed depending on ecological conditions. Accordingly, it is mostly found in the Mediterranean Region, Aegean Region, and other regions. Greenhouse in other words; Without being completely or partially dependent on the environmental conditions related to climate, factors such as temperature, light, humidity, and air are kept under control when necessary, and glass, plastic etc. are used to produce various cultivated plants and their seeds, seedlings and saplings all year round, to protect and display the plants. It is a high-system greenhouse cultivation structure that is made in different shapes by being covered with light-permeable material [2]. Greenhouses are movable structures that make it possible to grow cultivated plants economically in periods and places where climatic conditions are not suitable for growing plants outdoors and can provide the development factors necessary for plant production [3]. Although greenhouse cultivation has developed rapidly in temperate-hot climate zone countries that benefit from their ecological advantages, it has not been possible for cold greenhouse cultivation to reach the efficiency and quality level of heated greenhouse cultivation [4]. Heating or cooling costs in greenhouses are one of the most important factors affecting the economy of greenhouse farming. The costs of greenhouse cultivation have caused production to be limited due to the costs of cooling in hot regions and heating in cold regions. In order not to disrupt production and impose a heavy burden on the producer, the focus on renewable energy sources must increase. In recent years, research has been conducted to reduce energy consumption in greenhouse cultivation; It is directed to use new and renewable natural energy sources for heating purposes and to develop low-cost and highly efficient heating systems as an alternative to traditional heating systems that consume fossil fuels. The most significant renewable energy source, solar energy, can be utilized to heat greenhouses. This will reduce heating charges, which account for a significant portion of greenhouse agriculture's overall production costs, and subsequently, production costs. To protect today's energy availability and avoid environmental damage, using alternative energy sources instead of fossil fuels is a priority in greenhouse heating applications. Low-temperature waste heat energy from solar, geothermal, and industrial sources is one type of alternative energy source used in greenhouse heating [5].

In this study, meeting the heat needs of greenhouses through solar energy, which may be the most applicable among the natural energy sources that can be used in heating greenhouses, was examined. Nowadays, although using solar energy more effectively in greenhouse heating has gained great importance, some technical and economic problems are encountered in practice. Compared to traditional heating systems, the initial investment cost of solar heating systems is proportionally higher. During the daytime when the outdoor temperature is lower than the greenhouse indoor temperature, part of the greenhouse heat requirement is met by solar radiation absorbed in the greenhouse. Within the scope of the study, it was aimed to heat the greenhouse by using solar energy using two-store plastic greenhouse material with a floor area of 500 m2 for Mersin province. Additionally, a thermal analysis of the designed greenhouse was performed. The heat requirement of the plastic greenhouse is determined as 1 °C outdoor temperature and 15 °C indoor temperature. The total heat requirement required for ΔT = 7 °C temperature difference between the inside of the greenhouse and the outside environment during the coldest January night periods, which is the highest heat requirement of the plastic greenhouse, was designed for the solar energy heating system to be designed. In addition, the total daily heat requirement for average daily heating for January, the coldest month, was determined as 60 kW. It has been determined that a total of 750 m long and 51 mm diameter pipe should be used for the plastic greenhouse. It was determined that a total of 32 flat solar collectors, each with an absorber surface area of 1.8 m2, should be used in the heat collection unit.

II. MATERIAL AND METHOD

Plastic was selected for the greenhouse's double-layered architecture to cut expenses and minimize heat loss on chilly days. Plastic film covered greenhouses are common, particularly in many temperate nations. In our nation, plastic greenhouses are commonly utilized in areas with climates more suited for greenhouse farming. It is the goal of the greenhouse technology to cover a bigger production area under one roof. Consequently, designs for multi-compartment greenhouses with gutter connections are used. Gutter connections allow for more efficient natural ventilation and lower design expenses when creating greenhouses. Gutter connections are typically included in the design of multi-compartment block greenhouses. With these kinds of greenhouse plans, the whole production area is housed under one roof. The designed double-layer plastic greenhouse are given in Figure 1.

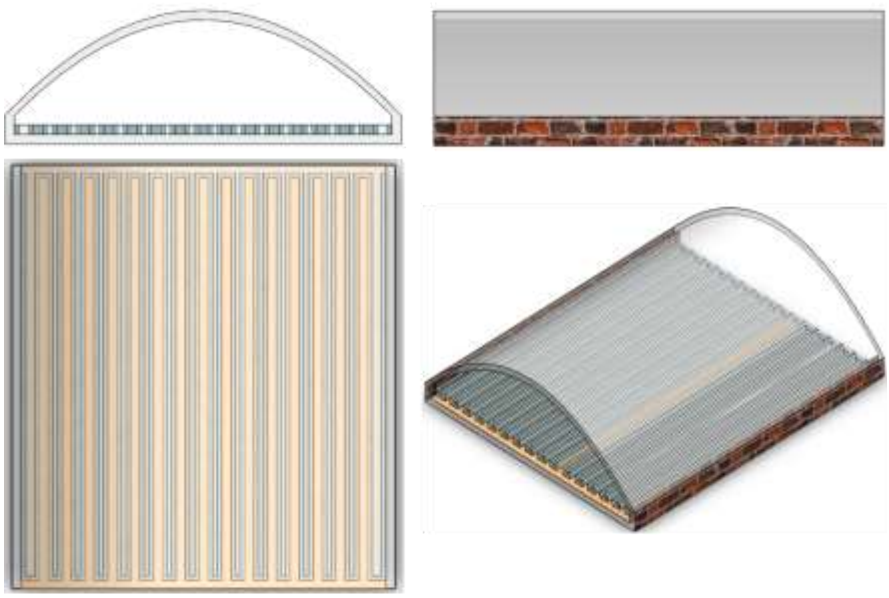

Figure 1. 3-D drawing of the greenhouse

Table 1. Dimensions of the designed greenhouse

Dimensions of the designed greenhouse	Measurements (m)
Width of greenhouse	20
Length of the greenhouse	25
Wall height of greenhouse	1
Height of the greenhouse	4

Mersin province was taken into consideration in this study, which was designed for greenhouse heating and daily storage of solar energy by sensible heat storage method using water. The schematic view of the solar greenhouse heating system is given in Figure 2.

Figure 2. Solar greenhouse heating system

During the daytime, the heat energy collected by the solar collectors will be stored in the heat storage unit, with the operation of the pump unit no. 1 indicated in Figure 2. Depending on the indoor temperature of the plastic greenhouse, pump unit number 2 will be operated to recover heat from the heat storage unit. In this case, fluid circulation will be provided between the heat storage unit and the heating pipes in the plastic greenhouse unit. During heat recovery periods, the operation of the electric motor that drives the pump unit used for fluid circulation between the plastic greenhouse and heat storage units will be controlled by a timer. In the solar active heating system, when the temperature of the heated water is higher than the water temperature required to be sent to the greenhouse (distribution temperature), the heated water in the system is circulated through pipes to heat the greenhouse. If no auxiliary heating system is used, solar heated water can be used to preheat the greenhouse or simply to protect it from low temperatures. In this case, where the operating temperature of the system is low, collectors are used more effectively. It is considered to use solar collectors to collect solar energy, which will be stored as heat energy in the heat storage unit. Solar collectors are systems of various types and shapes that collect solar energy and transfer it as heat to a fluid. Solar collectors are generally used for domestic hot water heating. The temperature they reach is around 70 °C. These systems are used to provide hot water for swimming pools and industrial facilities, as well as residences. Solar collectors: Depending on the heat carrier fluid, they can be divided into two groups: air and liquid type. Although air solar collectors are generally used in the heating and drying processes of residences and small commercial buildings, liquid solar collectors are used in the heating of large buildings, industrial heating processes and solar cooling applications. Since the heat transfer efficiency of water is higher, the temperature of the absorber plate in liquid solar collectors is only a few degrees higher than the heat carrier fluid inside. Liquid solar collectors collect more energy and have higher efficiency. Solar collectors from top to bottom; It consists of a top cover made of glass, sufficient space between the glass and the absorber plate, a metal or plastic absorber plate, rear and side insulation, and a casing that contains these sections. Solar collectors with dimensions of 1940 x 940 mm, each with an absorber surface area of 1.8 m^2, will be used in the heat collection unit. Automatic control can be provided for the heating system. Depending on the ambient temperature, the response of fluid temperature change is fast and reliable. The effect of the heating system on the soil on the greenhouse floor is small but significant. The horizontal and vertical temperature profile of the air in the greenhouse interior is quite smooth. In greenhouses with this type of heating system, the leaf temperature of the plants is very close to the air temperature. Air movement and direction in the greenhouse are generally suitable for greenhouse cultivation. It generally has positive effects for any cultivation system. With this type of heating systems: It is reported that early harvest, high yield, and quality product are obtained. In the greenhouse heating system, the inlet temperature of the heating fluid in the pipes is determined as 60°C and the return temperature is determined as 40°C. In addition, the total heat transfer coefficient of the double-layer polyethylene materials used as greenhouse cover was taken as 3.7 W/m^2K. If the heating fluid temperature is low, the heating pipe surface area needs to be increased. This may cause the lighting conditions of the greenhouse to deteriorate. In case the heating fluid temperature is low, low-temperature heating pipes generally need to be placed close to the soil surface to prevent light penetration into the greenhouse environment due to the increased heat exchanger surface area that needs to be used.

The amount of heat required per floor area for heating the plastic greenhouse to be installed, whose features are given in Figure 1 and Table 1, is determined from the equation below [5].

$$q_s = \frac{A_s}{A_t} u (T_i - T_o) - I\tau\gamma \tag{1}$$

Here; q_s, A_t, A_s, u, T_i, T_o, I, τ and γ are heat requirement per floor area (W/m^2), greenhouse floor area (m^2), greenhouse cover surface area (m^2), total heat loss coefficient (W/m^2°C), temperature of the greenhouse indoor air (°C), temperature of the outdoor air (°C), total solar radiation (W/m^2), total radiation transmittance of the greenhouse and total radiation to thermal radiation that is effective in increasing the greenhouse indoor temperature is the conversion rate respectively.

The total heat requirement of the greenhouse is calculated as follows, depending on the heat required for the floor area.

$$Q_s = q_s A_s \tag{2}$$

In this equality, Q_s, q_s and A_s are the total heat requirement of the greenhouse (W), heat requirement per floor area (W/m^2) and greenhouse floor area (m^2) respectively.

The heat requirement of the plastic greenhouse is calculated for night conditions in January, when solar heat gain is low or non-existent. Solar-powered active heating systems in greenhouses are designed to meet a certain proportion of the annual heat requirement. Heat losses occurring depending on the desired temperature in the greenhouse interior are considered and the annual heat requirement of the greenhouse is calculated. In the calculations made for the sizing of the greenhouse heating system with solar energy, it was considered that half of the total heat requirement of the plastic greenhouse to be installed in the winter periods when heating is needed the most is met by solar energy. The total heat loss coefficient is used as a comparison value for the heat energy consumption of greenhouses with different technical equipment. Total heat loss coefficient (u, W/m^2°C); It indicates the total heat loss from each m^2 of the greenhouse surface area for a 1 °C difference between the greenhouse indoor temperature and outdoor temperature. The total heat loss coefficient includes heat losses due to conduction and convection from the greenhouse, as well as heat losses due to thermal radiation changes. Although the greenhouse heat requirement can be determined with sufficient accuracy depending on the total heat loss coefficient, a more accurate estimate can be made by separately calculating the heat losses caused by conduction, convection, and thermal radiation from the greenhouse [5]. To determine the heating requirement in the greenhouse, the limit value of the indoor temperature must first be defined. Although it is necessary to provide the optimum temperature for plant development in the greenhouse, this may not be economically possible. Since the desired temperature value is different for many plant species in the greenhouse, the control of heating systems varies accordingly. To grow different types of plants in greenhouses, the indoor air temperature should be adjusted between 10-28 °C. The heat requirement of the designed plastic greenhouse was calculated based on an indoor temperature of 15 °C. In determining the outdoor temperature, the average of the lowest temperatures occurring in the coldest time of the year is considered, depending on the climatic conditions of the region where the greenhouse is located. In the heating system design, long-year temperature and solar energy values of Mersin province were taken into consideration. For the design of heating systems, the heat requirement of the plastic greenhouse to be installed was calculated based on 1 °C outdoor temperature.

The total heating pipe length that should be used in hot water heating systems in greenhouses is calculated as follows, depending on the total heat requirement of the greenhouse and the amount of heat gained from the unit length of the heating pipe designed to be used.

$$L_b = Q_s/Q_b$$
(3)

Here, L_b, Q_s and Q_b are the length of the heating pipe (m), the total heat requirement of the greenhouse (W) and the amount of heat gained from the pipe (W/m), respectively.

The total amount of heat passing into the greenhouse environment from the unit length of the heating pipe to be used as a heat exchanger in the plastic greenhouse is calculated from the equation below, depending on the inner and outer diameters of the pipe. It is envisaged to use a 51 mm diameter pipe as a heat exchanger for the heating system in the plastic greenhouse.

$$Q_b = \frac{4\pi L_b \Delta T_b}{\frac{1}{\alpha_i d_i} + \frac{\ln(\frac{d_d}{d_i})}{\lambda_b} + \frac{1}{\alpha_o d_o}} Q_r \quad (4)$$

Here; Q_b, L_b, ΔT_b, α_i, α_o d_o, d_i, λ_b and Q_r are the amount of heat gained from the pipe (W/m), heating pipe length (m), temperature difference (°C), inner surface heat transfer coefficient (W/m^2K), outer surface heat transfer coefficient (W/m^2K), pipe outer diameter (m), pipe inner diameter (m), heat conduction coefficient (W/m °C) and the amount of thermal power transmitted by radiation (W) respectively.

The difference between the air temperature in the greenhouse interior and the water temperature in the heating pipe (ΔTb) is calculated as the logarithmic average temperature difference.

$$\Delta T_b = \frac{T_i - T_o}{\ln\frac{(T_i - T_s)}{(T_o - T_s)}} \quad (5)$$

Here; T_i, T_o and T_s are the entry temperature of the water into the heating pipe (°C), the water exit temperature from the heating pipe (°C) and the air temperature in the greenhouse (°C) respectively.

After determining the amount of heat energy required to meet a certain proportion of the annual heat requirement for greenhouse heating, the collector area required to collect this energy is calculated. Solar energy collection efficiency of collectors; It depends on the solar radiation falling on the collector, the optical properties of the collector cover material and the absorber surface. The efficiency of the solar collectors to be used in the heat collection unit to be designed is considered as η_t = 60%. The collector area that should be used in the heat collection unit is calculated from the equation below.

$$A_t = \frac{Q_s}{I\eta_t} \quad (6)$$

Here, A_t, Q_s, I and η_t are the collector surface area (m²), the greenhouse heat requirement expected to be met by solar energy (kJ/day), the amount of solar energy coming to the collector surface (kJ/m² day) and the collector efficiency (%).

A mesh structure was created in CFD (Computational Fluid Dynamics) analysis for the designed greenhouse model. For this design, CFD analysis was carried out using Ansys software according to the mesh structure given in Figure 3. This greenhouse model has 8289756 elements and 1666077 nodes.

Figure 3. Mesh structure of the greenhouse model

The system is solved by applying boundary conditions and parameters to the mesh files taken from the programs. In the analyses, the outdoor temperature was accepted as 1°C, the temperature value accepted in January for Mersin province. The inner surface temperature of the greenhouse was accepted as 15 °C.

III. RESULTS

Considering the province's climate, the heat requirements of the plastic greenhouse intended for Mersin province were computed monthly. It was found that, as anticipated, the winter months have a higher heat requirement per greenhouse floor area because of the drop in outside temperature. In the province of Mersin, the average heat need of plastic greenhouses in January is 120 W/m^2. The total daily heat requirement for daily heating in January of the plastic greenhouse with a designed 500 m^2 floor area was determined as 60 kW. In the calculations made for the sizing of the greenhouse heating system with solar energy, it was considered that 60% of this determined heat requirement, 30 kW, should be met with solar energy. Heat transfer per unit length of 51 mm diameter pipes to be used as heat exchangers in the plastic greenhouse was calculated as W/m. Depending on this value, it was determined that a total of 750 m long and 51 mm diameter pipe should be used between the plant rows in the plastic greenhouse. Solar collectors with dimensions of 1940 x 940 mm, each with an absorber surface area of 1.8 m^2, will be used in the heat collection unit. It has been calculated that a total of 32 flat solar collectors should be used in the heat total unit. Indoor and outdoor temperatures for Mersin province were determined to be used in Ansys software. In the analysis, the outdoor temperature was accepted as 1°C for Mersin province in January. The inner surface temperature of the greenhouse was accepted as 15 °C. In the analyses, the temperature distributions of the greenhouse were examined. Figure 4 shows the change in the temperature distribution contour of the greenhouse model.

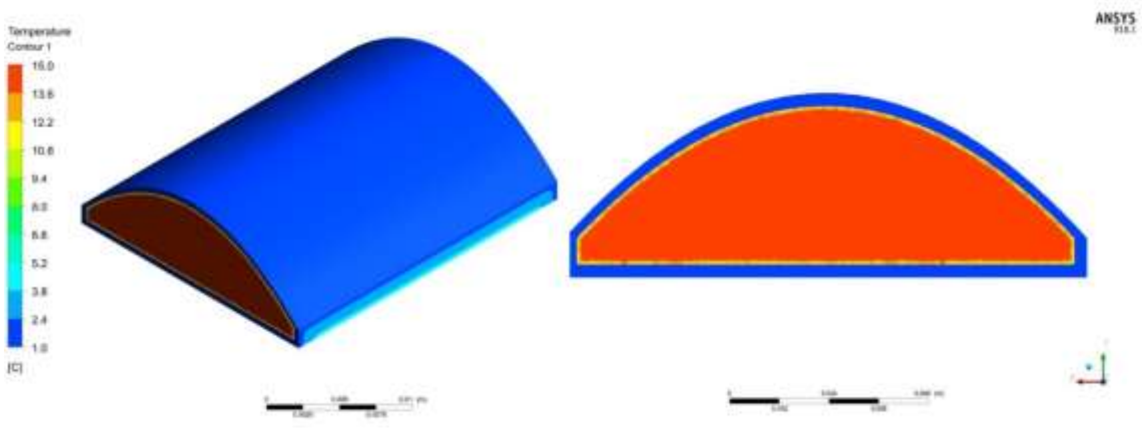

Figure 4. Temperature distribution contour of the greenhouse model

As can be seen from Figure 4, there is a temperature difference between the outdoor and indoor sides in the greenhouse model. It has been observed that the analyzes and mathematical modeling overlap with each other.

IV. CONCLUSION

In case of using solar energy for greenhouse heating; The greenhouse producer will make significant contributions to the country's economy, human health, and environmental protection. If solar energy is stored for greenhouse heating using the sensible heat storage method, heating costs, which constitute a large part of the total production costs of greenhouse agriculture, will decrease. As a result of preliminary calculations, it has been determined that 60-70% of the coal amount required for greenhouse heating will be saved with the solar energy heating system. Due to the decrease in heating costs, the production cost of products grown in greenhouses will also decrease. Reducing the production costs of products grown in greenhouses will facilitate the marketing of these products in foreign and domestic markets and will provide competitiveness, especially in foreign markets. It will contribute to social welfare as consumers will be able to purchase products grown in greenhouses at a cheaper price. Significant energy savings will be achieved due to the reduction in the amount of energy required to be used for greenhouse heating. In our country, which imports energy, a significant contribution will be made to the national economy, as the amount of foreign currency to be paid for energy imports will decrease. As an important result of energy saving, fossil fuel consumption for greenhouse heating applications will decrease, and the emission of CO_2 gas, one of the main gases that create a greenhouse effect in the atmosphere, will also decrease significantly. Thus, it will contribute to environmental protection. The heat storage method proposed in the study is simple in design and low in cost.

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